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# Surrogate thigh model for assessing impact force attenuation of protective pads

**Con Hrysomallis**

*Centre for Ageing, Rehabilitation, Exercise and Sport, School of Human Movement, Recreation and Performance, Victoria University, Melbourne, Australia*

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**Summary** A thigh contusion is a common sports related injury that can result in disability and time away from activity. Thigh pads can be worn to help reduce injury occurrence and severity. To evaluate the relative effectiveness of protective guards a thigh model is required. This study utilised data generated from impacts on human volunteers and cadaver material to select a surrogate soft tissue component for a thigh model. This component was attached to a stainless steel beam that represented the femur. The model was instrumented with an internal transducer to measure local peak force. This parameter provided a measure of the impact force attenuation of protective equipment. Initial tests were conducted on cricket thigh pads. The thigh model can be used to assess the relative effectiveness of thigh guards and has the potential to determine whether the ideally sought lightweight low bulk pads offer similar protection as other bulkier pads.
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## Introduction

Thigh contusions or hematomas are often associated with athletic injury and most commonly occur in young males engaged in contact and combat sports. Epidemiological data have revealed that thigh contusions occur in a number of sports: rugby,[3] karate,[13] soccer,[14] cricket[11] and Australian football.[12] The majority of thigh contusions are not serious but they do cause performance impairment and time away from activity.[13] Two uncommon but potentially serious complications of severe thigh contusions are myositis ossificans traumatica and compartment syndrome.[6,17]

*E-mail address:* Con.Hrysomallis@vu.edu.au.

Protective thigh pads are worn in the hope of reducing the incidence and severity of injury as well as protecting a recently injured area from further injury.[1] A prospective intervention study found that thigh pads were effective in preventing hematomas in adolescent Australian footballers but interfered with heat dissipation on warm days.[9] Thigh guards may vary in their composition, weight, bulk and heat dissipation. Using large scale intervention studies to determine the effectiveness of different thigh pads may not always be feasible due to resources and time required. Laboratory assessment of protective equipment can provide useful information to help design optimal equipment. The force attenuation of protective equipment may be determined from impacts delivered to a physical surrogate. There are physical leg models in exis-

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tence such as the basic curved steel anvil used in assessing protective cricket equipment[2] and the lower limb of the sophisticated Hybrid III crash test dummy.[7] Neither of these however has been specifically designed to measure the soft tissue (combined skin, adipose tissue and skeletal muscle) response to transverse blows to the long axis of the thigh.

One approach to develop an appropriate physical thigh model is, first to determine the mechanical response of human volunteers to non-injurious impacts. These data may then be pooled with cadaver data[8] to extend the results into the injury domain. This would provide the criteria upon which to assess the biofidelity of the synthetic material used in the model.[5] Instrumenting the model with an internal transducer would then allow the relative effectiveness of protective equipment to be determined. The aim of this investigation was to construct a thigh model with a biofidelic soft tissue component capable of assessing the blunt impact force attenuation of protective thigh pads.

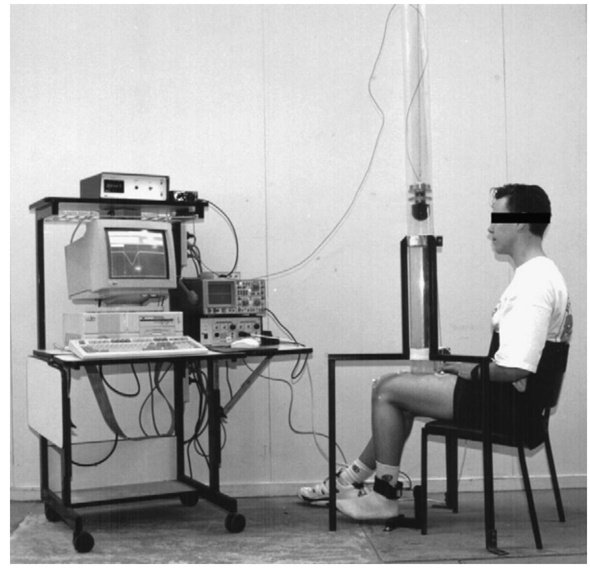

**Figure 1** Experimental set up for drop tests on human volunteers.

## Methods

### Human volunteer tests

Eighteen physically active males participated in this investigation. The project was approved by the institutional ethics committee and voluntary, informed consent was provided by the participants. The subjects were screened for previous lower limb injuries. Anthropometric data were collected: height, body mass, mid thigh girth and mid thigh skin fold thickness (mid thigh was defined as mid way between most lateral aspect of the greater trochanter of the femur and proximal patella border). Subjects were seated with their knee angle at 90° and Velcro straps applied for stabilisation across the waist, chest and ankle (Fig. 1). Surface electrodes were placed on the skin overlying rectus femoris. The amplified, raw EMG signal was displayed on a cathode ray oscilloscope (CRO). A 2.23 kg striker with a steel hemispherical impact surface, diameter of 73 mm and instrumented with a piezoelectric accelerometer (Brüel & Kjær 4384) was used for drop tests on the anterior mid thigh of the subjects. A transparent acrylic tube supported by a metal tripod was used to guide the fall of the striker. Drop tests were performed while the thigh muscles were relaxed (negligible EMG activity). The subjects were instructed to turn their heads away and concentrate on the CRO. They could not clearly see or hear the striker drop. Based on pilot work, it was decided to attain data from drops ranging from 10 to 100 cm with most 50 cm and under. These impacts represented low-speed impacts. Subjects who experienced the higher drop heights were not exposed to as many drops. For the subjects to withstand a number of drops, the higher drops were usually performed towards the end of the sequence. There were approximately 3 min intervals between successive drops. Data were captured with the Test Partner system (Lansmont Corporation, California). The mechanical response was determined by the peak deceleration of the striker.

To determine the reliability of the procedure, the intraclass correlation coefficient (ICC) was calculated for drop tests carried out on one subject 34 days apart. Data from drop tests 10—50 cm in 10 cm increments were captured.

### Cadaver tests

The cadaver material comprised of a fresh frozen pair of lower limbs severed at the level of the hip with parts of the coxal and sacral bones attached. This maintained the integrity of the attachments of the thigh muscles. The limbs were thawed overnight and then submerged in a water bath at a temperature of 37 °C prior to testing. Once removed from the bath, anthropometric measurements were taken. The limb was then placed on steel stands and fixed in position by timber brackets and Velcro straps. To avoid excessive compression, repetitive drops on the mid thigh location were kept to a minimum. Two drop tests from heights of 10 and 50 cm were performed on the left thigh and one drop from 130 cm was carried out on the right

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